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POWER GENERATION POTENTIALS OF MAJOR GEOTHERMAL FIELDS IN TURKEY

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ABSTRACT

In this study, potential of electrical power generation estimates for geothermal resource fields with sufficient information available in Turkey are calculated. Estimates are obtained using the methodology based on volumetric reserve estimation approach introduced by USGS. A stochastic approach using Monte Carlo simulation technique is implemented to account for uncertainties involving some input parameters. Electrical power potential capacities of those fields are estimated and the results are reported.

INTRODUCTION

The present installed electricity generating capacity of Turkey is ~$40.5x10^3$ MW_e. Official statistics (Ministry of Energy and Natural Resources) show that natural gas, hydro, coal, and liquid fossil fuels and renewables provide 40%, 30%, 25%, and 5% of the total electricity of the country, respectively. Geothermal energy remains as a small contributor to the power generation capacity of Turkey. Geothermal plants constituted only 0.05% of the installed generating capacity and provides around 0.06% of the total electricity. The installed capacity of geothermal power plants in Turkey is presently 24.7 MW_e. There will be modest addition to geothermal (7.5 W_e), and another 54.5 MW_e (9.5 MW_e+45 MW_e) will be in line within 2 years.

Turkey appears to be rich in geothermal resource potential, but, there have not been proper estimates about them. We have recently started a project for estimation of potentials of these resources and presented our first findings at the 32nd Stanford Geothermal Workshop (Satman, et al., 2007).

After installation of a binary power plant in Salavatli-Sultanhisar geothermal field, interest in developing geothermal resources for power generation has substantially increased. Therefore, we have focused on power generation potential of known middle and high enthalpy geothermal resources.

These geothermal resources have been explored by geoscientific surveys up to various levels. While a few wells have been drilled in some of them, several even a few tens of wells have been drilled in some others. In other words, the degree of information is different for each resource. Only one field (the Kizildere geothermal field) has production history which might enable reservoir modeling studies that in turn may provide more reliable power generation capacity estimates.

METHODOLOGY

Estimating power generation capacity of a geothermal reservoir is a complex problem. There is no direct methodology for determining the energy (electric or direct heat) production capacities of a geothermal reservoir. The calculations conducted for oil reservoirs and water aquifers are mostly based on the fluid content in place and productivities of individual wells and the field. Modeling studies are aimed to define the future production performance and the physical changes in the reservoir.

Geothermal reservoirs are fractured systems and the heat is stored in fluid as well as in the rock. A geothermal system is, without doubt, extremely complicated, and therefore, energy and material balance should be considered in assessing this sort of resources. Estimating a reserve (oil or geothermal) requires substantial data. At early stages of reservoir exploration and development the field and production data are scarce. That's why simple production evaluation, volumetric–performance techniques and different modeling approaches are applied.

A number of approaches are used to estimate the total amount of heat or power available from a geothermal field. These are as follows:

- Stored heat
- Total well flow
- Areal estimates

- Decline curve analysis
- Lumped parameter models
- Reservoir simulation

Stochastic and risk analysis methods are frequently used to estimate the range and probable distribution of oil and geothermal reserves when there is considerable uncertainty. Known parameters are extrapolated into the probable distributions using stochastic techniques. Then the outcome from those simulations is evaluated using a risk analysis approach. Brook et al. (1979) used a similar approach to compute the distribution of accessible geothermal resource base within the United States. The same approach can be utilized to estimate the geothermal energy reserve distribution for high enthalpy geothermal fields.

To determine the capacity of a geothermal system, pivoting parameters such as reservoir size, the contained fluid and heat within the system are estimated by using different approaches. In this paper, the potential of the eleven major fields already discovered and explored to some degree in Turkey are estimated volumetrically by taking into account of heat contained both in the rock and fluid. Since available information is not sufficient to conduct more sophisticated reservoir evaluation approaches, a volumetric approach is applied. The potential of geothermal fields is estimated by considering stored heat in the reservoir, the recoverability of heat energy, conversion efficiency from heat energy to mechanical form of energy, heat load and load factor. In other words the major geothermal reservoirs are considered as a heat-producing systems declining over time from an initial reservoir temperature to an abandonment temperature (100^{o}C-180^{o}C, depending on conversion cycle.

Muffler and Cataldi, (1978) defined the basic principles and assumptions about useable stored heat calculations. Their approach was deterministic and can not define the uncertainties on parameters such as fluid and rock properties, reservoir volume and recovery factor.

Since similarities in the geological environment in most of the fields studied in this paper are well known, available porosity, density and fluid properties data from well-studied geothermal reservoirs such as the Kizildere and Germencik geothermal fields may be extended to the other geothermal systems in Western Anatolia. The available data for all eleven fields are not adequate for a deterministic approach to estimate the geothermal potential of the fields, with the exception of the Kizildere field. In the presence of such uncertainties in the geological, geophysical and reservoir data, stochastic simulation technique based on the distribution sampling process is considered to be more suitable.

In the context of this study, simulation is a method in which dependent variable (i.e. accessible heat) is calculated many times with varying input variables. Simulation under uncertainty has been used as a risk analysis technique for petroleum and natural gas exploration extensively (Newendorp, 1975). The simulation method used in this study to determine the geothermal potential of major geothermal systems of Turkey is the Monte Carlo simulation technique. Parameters used to calculate the potential of a reservoir should have single values in nature. But only a small portion of the pertinent data for the geothermal fields is known with a high level of certainty ahead of the time. Usually all we know is the range of most probable values for each of such parameters. To reflect the uncertainties in the parameters determining geothermal energy potential of individual systems, variables such as aerial extension, reservoir temperature, and formation thickness should be quantified by separate probability distributions.

The independent variables are sampled at each step of Monte Carlo simulation, and thus complete representation of all possible outcomes can be achieved if the number of steps becomes large. Sampling in Monte Carlo simulation process is intended to retrieve possible values for independent variables selected randomly from assigned probability distributions. The set of sampled independent parameters are then used to calculate the dependent parameters. Each sample set computed at each simulation step represents a possible combination of input parameters (Newendorp, 1975).

Monte Carlo sampling refers to sampling from an assigned probability distribution using computer generated random or pseudo-random numbers between 0 and 1. In the Monte Carlo sampling technique the outcome is entirely random and will fall anywhere within the limits of an assigned input distribution (Newendorp, 1975).

GEOTHERMAL POTENTIAL ESTIMATION

In this study, collected data such as aerial extension, reservoir temperature, formation thickness, porosity, reservoir rock density, specific heat and formation fluid specific heat are expressed in triangular and uniform distributions. In triangular distribution each parameter is represented with minimum, most likely and maximum values. Triangular distribution is especially suitable when actual data is limited. Aerial extensions of the structures are obtained from resistivity anomalies, and reservoir temperatures are computed by applying different geothermometers to the samples taken from hot springs and well fluids. Other parameters such as porosity and rock density are taken from the data collected for different fields, since the fields studied in this paper have similar geological environment.

In the first stage, a number of simulation runs are carried out to estimate the individual and overall accessible geothermal heat potential of the eleven fields discussed here. In the case of individual fields the independent variables are sampled and the accessible geothermal energy is computed by using the following volumetric equation (Muffler and Cataldi, 1979):

$$H_{Total} = H_R + H_F$$
$$= (1-\varphi)\, c_R \rho_R\, V\,(T_R - T_A) + \varphi\, c_F \rho_F\, V\,(T_R - T_A) \qquad (1)$$

where

H	Heat energy, J
φ	Porosity, %
c	Specific heat, kJ /kg-°C
ρ	Density, kg/m^3
V	Hot rock volume, m^3
T	Temperature, °C

The subscripts R, F and A stand for rock, fluid and atmosphere, respectively.

The density of the hot reservoir fluid is considered as a function of temperature only and computed from the following correlation:

$$\rho_f = \frac{1000}{A + 3.0564410^{-6}(T_F + 273.15)^2} \qquad (2)$$

where

$$A = 1.16849 - 0.001477(T_F + 273.15)$$

A step size of 10,000 is set for individual geothermal system simulation runs. The larger number of steps guarantees that all possible outcomes within the current scenario are taken into account to determine realistic geothermal potentials of major fields. Eleven potential geothermal fields in Turkey are simulated individually and then a mean value for the total potential geothermal energy is computed.

As discussed earlier the “Stored Heat” method proposed by Muffler and Cataldi, (1978) is used in this study to estimate power generation potentials of major fields in Turkey. The same approach with Monte Carlo simulation was also used by Brook, et al. (1978) to estimate US geothermal resources. Lovekin, (2004) used similar approach to estimate geothermal resources available for development in California and Nevada.

Table 1. Individual Fields’ Power Generation.

Fields	Power Generation, MW$_e$		
	10%	50%	90%
1	1.8	4.4	8.4
2	5.7	10	17
3	5.1	11	22
4	9.2	24	42
5	20	46	84
6	34	52	78
7	40	65	106
8	67	102	150
9	88	111	140
10	61	116	207
11	238	363	536

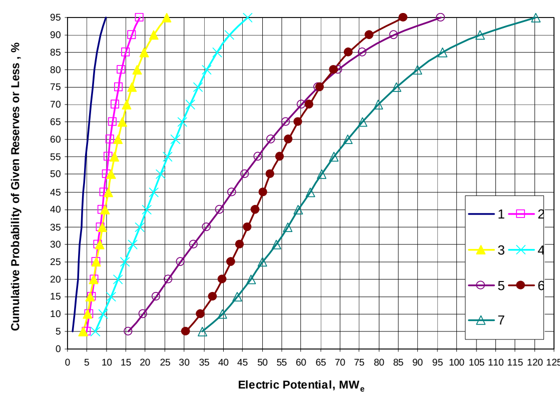

Figure 1. Cumulative frequency graph of individual power generation potentials of seven geothermal fields in Turkey.

When we are computing potentials in the model, we have assumed an industrial lifetime of 30 years and abandonment temperature of 100°C. The simulation results are illustrated as cumulative probabilities in Fig. 1 and Fig. 2 and summarized in Table 1 as 10%, 50% and 90% probability values of geothermal resource capacities for individual fields’ power generation.

Since there will be bidding for transferring the consents of some these fields from the state to the private sector in near future, the names of fields given in Table 1 and Figures 1 and 2 have not been disclosed to avoid influencing the bidding process.

Figure 3 illustrates total power generation capacity of eleven major fields, and Table 2 shows 10%, 50% and 90% values of total power generation capacities of those resources in Turkey.

Table 2. Total Electrical Power Generation.

Fields	Power Generation, MW_e		
	10%	50%	90%
Total	570	905	1389

Taking into account the SPE's approach for reserve determination, we can define 10 percentile as proven, 50 percentile as probable and 90 percentile as possible reserves (Clotworthy et al., 2006). As can be seen from Table 2, eleven major fields have 570 MW_e of proven, 905 MW_e of probable and 1389 MW_e of possible geothermal reserves for power generation.

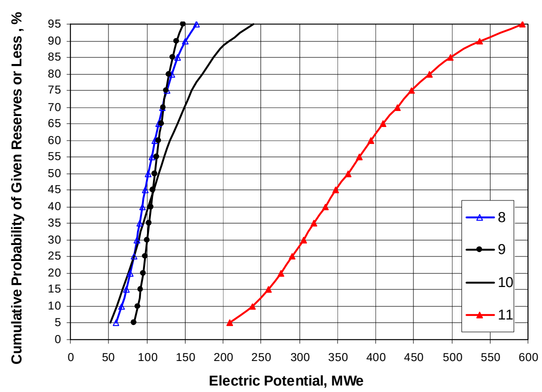

Figure 2. Cumulative frequency graph of power generation potential of four major geothermal fields in Turkey.

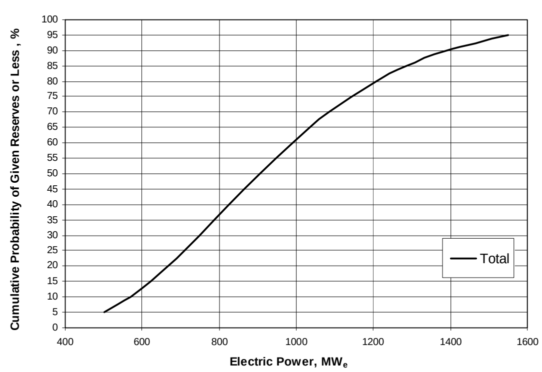

Figure 3. Cumulative frequency graph of total power generation potential of all major geothermal fields in Turkey.

After estimating major fields' electric power generation capacities, resource capacities on the basis of thermal units were also studied for estimation of geothermal resources of those fields available for direct and indirect utilization. Therefore, we have also calculated total power generation potential of major fields in thermal units. Figure 4 illustrates those potentials in thermal units, computed for reference temperatures of 40°C and 15°C. Table 3 also shows 10%, 50% and 90% values of total power generation capacities of all known major geothermal resources in Turkey in thermal units.

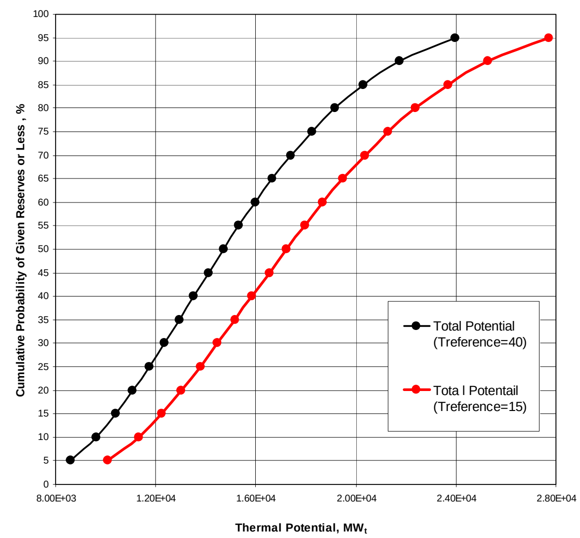

Figure 4. Cumulative frequency graph of total thermal energy power potential of major geothermal fields in Turkey with different reference temperatures.

Table 3. Total Thermal Energy Power Potential of Major Fields.

Fields	Thermal Capacity, MW_t		
	10%	50%	90%
Thermal Capacity, (T_{ref}=15)	11307	17234	25277
Thermal Capacity, (T_{ref}=40)	9637	14721	21728

In terms of thermal energy power of major fields, Turkey has 11307 MW_t of proven, 17234 MW_t of probable and 25277 MW_t of possible reserves for T_{ref} of 15°C. Thermal energy reserves for T_{ref} of 40°C can also be seen in Table 3.

DISCUSSION AND RESULTS

In his assessment of reserve proving methods, Grant (2000) evaluated stored heat (deterministic) approach as a method with significant weaknesses. His principal objections were: (1) little evidence to validate recovery factor and (2) regions with low permeability within the defined rock volume may not contribute to the producible reserves. Therefore, this method is often overestimates the field capacities.

While we agree on the concerns of Grant (2000), we are also aware that there is no other approach to estimate resource potential with limited data. Other methods listed in the previous section require substantial amount of data with considerable field production history. It is not always possible to find good quality geoscientific surveys, extensively tested wells and a production history to conduct reservoir engineering performance studies, lumped parameter models and simulation runs.

Of the eleven fields studied here, there are some fields which are studied extensively with more than 20 wells whereas there are some others with limited degree of exploration and drilled wells, and even some with one resistivity survey and one well. Geological and geochemical studies and geophysical surveys have been conducted in all examined fields, and multiple geophysical surveys (resistivity, magnetic, CSAMT, MT, gravity, SP, seismic, etc., whichever available) in most of them were considered. Our experience indicates that 5 to 10 ohm-meter resistivities for the geothermal fields in Western Turkey are very much indicative of high temperature, provided that they have similar TDS values. Therefore, the magnitudes of the anomalies of most of the fields are fairly known and defined.

Most of the resources are found in Menderes Massif and they are mostly tapping the geothermal fluid from the same geological environment. The Menderes Massif is one of the largest metamorphic massifs in Turkey, measuring roughly 200 km N-S, and about 150 km E-W in Western Anatolia. It can be described as a dome-like structure, broken by faulting during the alpine orogeny. The Menderes Massif includes a core of paragneisses and orthogneisses wrapped in a variety of schists and dolomitic marbles. These rocks have been intruded by a number of granites. The rock and fluid properties are mostly similar. In some extensively studied fields rock properties are determined from the well logs and lab tests and projected to other fields where there is no this sort of data available.

An extensive geochemical survey is also conducted on all fluids from existing wells and hot springs (Erisen et al, 1996 and MTA, 2005), and using geothermometers temperature distributions are specifically obtained for each field.

Distributions of reservoir volume are determined by combining geophysical surveys with geological and drilled deep well data. Three dimensional temperature simulation results, wherever available, provided us specific temperatures with dependent volumes that were very valuable for reducing uncertainty in Monte Carlo simulation.

In order to mitigate overestimates we used Monte Carlo simulation that would minimize the biased parameters. The distributions were justified with measured data. We also used dependent variables wherever have found dependency between variables since treating distributions separately in the models when they are dependent would give in extreme results in both directions enlarging uncertainty belt. We have also investigated uncertainties on the results, and found out that uncertainties are reduced substantially after using dependent variables.

Serpen (2001) conducted a sensitivity analysis on model parameters and concluded that the parameters affecting the results are, in the order of, volume, recovery factor and temperature. Some of our field volumes are defined based on 3D temperature distributions and geophysical surveys. As for the recovery factors we tried to remain in the conservative side, taking into account of report from the USGS that past experience showed lower recovery factors for the exploited US geothermal fields (Williams, 2007). We have used recovery factors with lower values than the ones found in the literature.

To avoid overestimations we have also tested parameters of our stochastic model with results of lumped parameter model runs in some well studied geothermal fields.

By using a deterministic type of an approach, Satman et al. (2007) presented results related to the identified geothermal capacity of all geothermal occurrences discovered in Turkey considering the flow rate and temperature data of the produced fluids. They concluded that the identified geothermal energy capacity was 3700 MW_t based on a reference temperature of 20^oC. Results presented here differ from Satman et al.'s results, because our potential results were obtained using a probabilistic type of approach based on Monte Carlo simulation. The second major difference is that Satman et al.'s results employed flow rate and temperature data of the produced fluid and did not take into account the in-situ thermal capacity of the fields whereas our results employed the field's in-situ volume, temperature, and rock and fluid data and calculated power generation potential and thermal energy potential. Therefore the capacity and potential figures differ from each other, expectedly.

Our continuing efforts are concentrated in collecting extensive and updated geological, geochemical, geophysical and production data. With addition of new, revised, and updated data better and more accurate estimates of the geothermal energy capacity and potential will be possible. Further modeling studies to estimate the assessing energy that can be extracted including lumped parameter modeling and some simulation studies as well as deterministic and probabilistic approaches as discussed in this paper are to be utilized to obtain better estimates of geothermal potential of Turkey.

CONCLUSIONS

In the light of above mentioned the following results are obtained:

- Total and individual power generation potentials of eleven major fields in Turkey are estimated in terms of proven, probable and possible reserves.
- Total and individual thermal energy potentials of those eleven fields are also estimated.

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